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Conformal Antenna Research in the US

Robert J. Mailloux
Air Force Research Laboratory
Sensors Directorate
80 Scott Drive
Hanscom AFB, Massachusetts, 01731-2909, United States
Telephone: 781.377.3710
Email: *Robert.Mailloux@hanscom.af.mil*

Abstract—Within the United States, interest in conformal and low profile antennas is in response to space and airborne requirements, and also to the volume constraints of shipborne radar.

Elements and arrays on generalized surfaces have also been analyzed using the finite difference time domain (FDTD) and finite element (FEM) methods. Analytical results for antennas on electrically larger bodies have been obtained using a combination of the Method of Moments (MOM) plus quasi-optical techniques. Recent work extends the utility of the hybrid methods using new Green's functions developed from the Uniform Geometrical Theory of Diffraction (UTD) to elevate the mutual coupling between elements on a uniformly coated, perfectly conducting, but otherwise arbitrarily shaped convex surface.

In addition to advances in analytical treatments, a number of small arrays have been built conformal to cylinders and other metallic structures. Fully electronically scanned arrays have been developed for airborne satcom at SHF and EHF frequencies. Arrays with dimensions large compared to the local radius of curvature will also be discussed, including an ultra wide band UHF radar array

I. Introduction

Progress in both theoretical analysis and practical implementation of conformal antennas has resulted in response to the demands for conformal aircraft and spacecraft, as well as flush mounted shipboard antenna systems. Gain requirements for these systems have lead to arrays that, in many cases, are larger than the local radius of platform curvature, and hence must be modeled as conforming to the host platform.

In addition to analytical studies, there has been work on the difficult problem of developing thin, conformable antenna hardware. The paper will give several current examples of this new technology.

II. Analysis

Integral equation solution by the Method of Moments (MOM) remains a particularly useful (and exact) analysis of antennas conformal to structures for which Green's Functions exist. These include the most common surfaces, cylinders, spheres and cones. More complete structures are often treated with finite difference time-domain (FDTD) or finite element methods. Studies of elements on electrically large and more complex bodies have been obtained using combinations of MOM plus quasi-optic techniques, and by Finite Element Boundary Integral (FE/BI) methods, in which the finite element mesh terminates in a stated boundary condition.

Rojas and colleagues have developed efficient numerical and analytical techniques based on steepest descent path integration, to evaluate approximate Green's Functions for perfectly conducting, dielectrically coated convex surfaces. In the most recent publication [1] the approach extends uniform theory of diffraction (UTD) methods, obtaining rapidly converging series for relatively large (3λ radius) coated cylinders, and presents very accurate results even for arbitrarily small separations of field and source points. Figure 1 shows the evaluation of mutual impedance between axially and circumferentially directed current sources on a coated cylinder. This comparison of the new steepest descent path integration (SDP) with the eigenfunction solution results attest to the high degree of accuracy made available by the new Green's Function approximations.

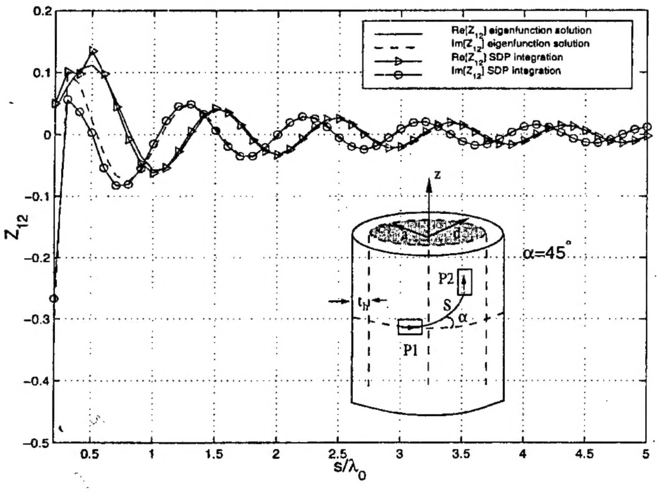

Figure 1 Real and imaginary parts of the mutal impedance between *z*- and *?*-directed current sources for a coated cylinder with $a = 3\lambda_0$, $th = 0.06\lambda_0$, $e_r = 3.25$ (Frank & Rojas, Ref. 1)

Finite element boundary integral (FE/BI) techniques are capable of handling large bodies, but in addition, these offer the flexibility to model complex geometries and material interfaces. The procedure can be accelerated using fast integral methods to speed up the matrix vector products and reduce memory requirements associated with the boundary integral (BI) equations. Some new results [2], shown in Figure 2, show the radiation patterns of a four arm archimedian spiral on cylinders of various radii. The figure at top represents the spiral excited in the mode with 90° phase advance per arm, and the one at bottom is excited with 180° of progressive phase shift per arm. The FE/BI results demonstrate that the shadow region pattern fall-off is faster for larger radii because of reduction of the creeping wave over the longer path length.

Fully electronically scanned arrays have also been developed for airborne satcom at SHF and EHF frequencies. In many cases, the aircraft radii of curvature are large compared to the array size, and so the arrays can be planar and flush mounted without having to conform to the cylinder. This technology has been under development since the mid-1980s by the US Air Force and NASA, and is now being incorporated into a number of military and commercial satcom programs.

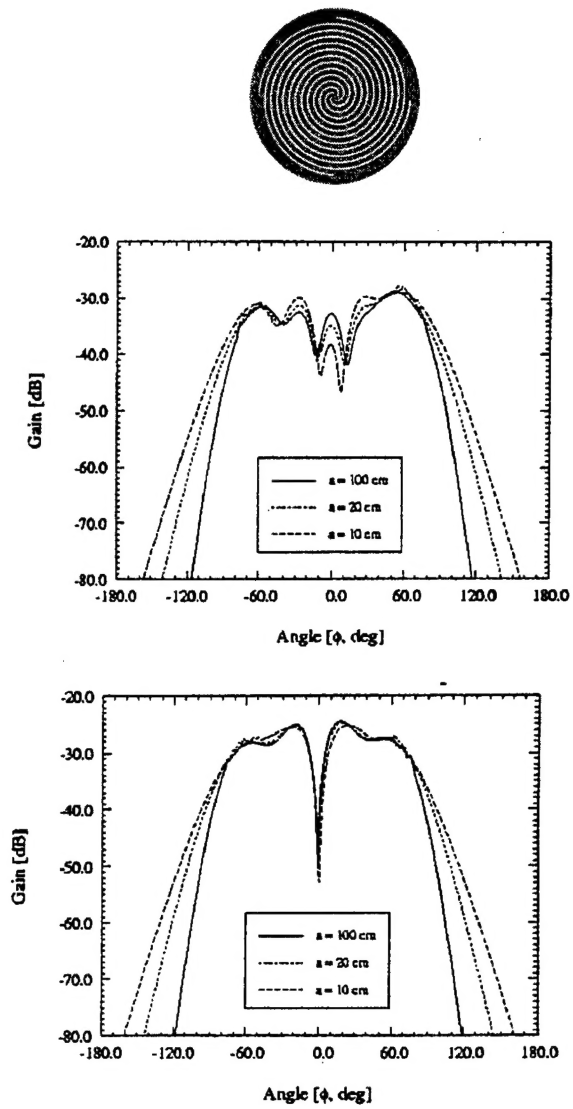

Figure 2 Radiation patterns for mode 1 (top) and mode 2 (bottom) at 11.5 GHz for the spiral antenna shown above. (Macon et.al., Ref 2)

Figure 3 shows 20 GHz (receive) and 44 GHz (transmit) brassboard antennas developed by Boeing Corporation for the US Air Force ICAPA (Integrated Circuit Active Phased Array). The arrays each contain 91 elements, and have in-line solid state modules that provide amplification and

phase shift. A 44 GHz transmit module is also shown in the figure. These arrays, with radiating circular waveguide apertures, have demonstrated scanning in excess of 60 degrees in all planes, and are predicted to have approximately 5 dB scan loss at 70 degrees. A more recent version of these arrays, designed to be intentionally mismatched at broadside, has scan loss of approximately 3 dB at 60 degrees of scan; thus closely approximating the cosine of the scan angle.

Figure 3 ICAPA antennas using in-line modules; ICAPA 44-GHz module *(Courtesy of Boeing Corporation.)*

These developments have led to a full line of arrays, including the three Satcom receive arrays shown in Figure 4 at 8, 12, and 20 GHz. The small arrays shown here have only 16 elements, and depth of 1.4 inches at 8 GHz, 0.94 at 12 GHz, and 0.75 inches at 20 GHz. Other arrays developed with this technology include a 256 and 4000 element versions for the US Navy at 20 GHz and arrays at 8 and 12 GHz for the US Army. The array elements are dielectric loaded circular waveguides excited by switchable left and right-handed circularly polarized modules. The modules have 4 phase shifter bits and an extra bit to select the polarization. They are hermetically sealed and are coupled to the circular waveguides by orthogonal probes.

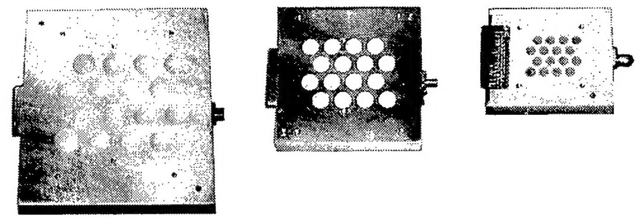

Figure 4 STATACOM Receive Phased Arrays (l-r): 8 GHz, 12 GHz, 20 GHz (Courtesy of Boeing Corporation)

A unique "conformal" array is the ultra wide band (4:1) UHF antenna developed by J. J. Lee and colleagues [3]. This array, sketched in Figure 5, could be mounted in the belly of an airborne platform, under a shallow radome only a quarter wavelength deep at the low end of the UHF band.

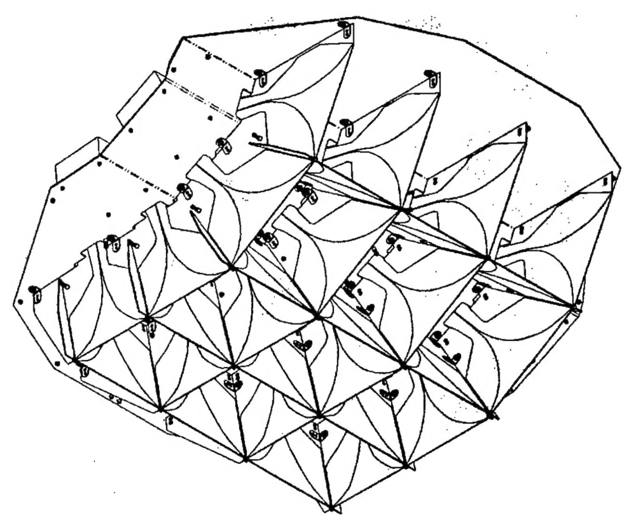

Figure 5 The "egg-crate" antenna has 16 elements with vertical polarization and 12 elements with horizontal polarization

The antenna is a dual-linearly polarized array consisting of 4x4 elements in the vertical polarization and 3x4 elements in the horizontal polarization. These elements were orthogonally interlocked in a rigid "egg-crate" structure. The radiating elements in each polarization have been grouped into three subarrays, which each powered by a solid state transmitter through a polarization switch.

To improve antenna efficiency and protect the transmitters, each channel was matched to have an input VSWR less than 2:1 over 90% of the band. Good impedance match over a wide band was achieved by feeding each element with a tapered quasi-TEM slot line, which transforms a 50-ohm input impedance to a 120-ohm radiation impedance.

III. CONCLUSIONS

The theoretical treatment of conformal antennas and arrays continues to advance with asymptotic and numerical solutions leading to progressively larger and more complex geometrics. The technology aspects of conformal arrays have also advanced, with thin light weight array modules at SHF and EHF, and accurate modeling of platform mounted arrays at UHF.

IV. REFERENCES

[1] V.B. Frank, R. Rojas, "Efficient Computation of Surface Fields Excited on a Dielectric-Coated Circular Cylinder," IEEE Trans. AP-48, No. 10, Oct 2000, pp. 1507-1516

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